STATEMENT

I, Hiroyoshi TERAOKA, residing at Ark Mori Building 13F, 12-32, Akasaka 1-chome, Minato-ku, Tokyo 107-6013, Japan, hereby state that I have a thorough knowledge of the English and Japanese languages and that the attached document is an accurate English translation of the Japanese specification of Japanese Patent Application 2002-290519 filed on October 2, 2002, upon which the present application claims a priority.

Declared at Tokyo, Japan

This 20th day of April 2006

Hiroyoshi TERAOKA

PATENT OFFICE

Japanese Government

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[Title of the Invention] ORGANIC EL DISPLAY

[Claims]

[Claim 1] An organic EL display equipped with an organic EL device having an organic material sandwiched by at least two electrodes, comprising:

a light emitting layer which emits light;

a front reflecting area arranged on the side of a viewer with respect to said light emitting layer; and

a rear reflecting portion arranged on the side opposite to the viewer with respect to said light emitting layer, wherein

the optical film thickness of said organic material, intensity reflectivity R_1 at said front reflecting area and intensity reflectivity R_2 at said front reflecting area are adjusted so that the external light intensity reflectivity of said display viewed from the viewer is 10 % or less by an optical interference effect.

[Claim 2] An organic EL display according to claim 1, wherein the relationship between said intensity reflectivity R_1 and intensity reflectivity R_2 is expressed by

$R_1 \leq R_2$.

[Claim 3] An organic EL display according to claim 1, wherein the relationship between said intensity reflectivity R_1 and intensity reflectivity R_2 is expressed by

[Equation 1]

[Claim 4] An organic EL display according to claim 1, wherein the relationship between said intensity reflectivity R_1 and intensity reflectivity R_2 are approximately equal to each other.

[Claim 5] An organic EL display according to claim 1, wherein said intensity reflectivity R_2 is adjusted to be 5 - 50 % to increase the efficiency of externally extracting EL light.

[Claim 6] An organic EL display according to any one of claims 1 to 5, wherein said front reflecting area is composed of a substrate and at least one transparent or semi-transparent film.

[Claim 7] An organic EL display according to claim 6, wherein said transparent or semi-transparent film includes either one of said two electrodes.

[Claim 8] An organic EL display according to any one of claims 1 to 5, wherein said front reflecting area is an interface between an electrode and the substrate of the organic EL device.

[Claim 9] An organic EL display according to any one of claims 1 to 5, wherein said front reflecting area is an interface between an electrode and a transmissive film of the organic EL device.

[Claim 10] An organic EL display according to one of claims 1 to 5, wherein said front reflecting area is composed of air and a transparent or semi-transparent film.

[Claim 11] An organic EL display according to one of claims

1 to 5, wherein said rear reflecting area is an electrode of said organic EL device.

[Claim 12] An organic EL display according to one of claims 1 to 5, wherein said rear reflecting area includes a plurality of reflective, transmissive or semi-transmissive films.

[Claim 13] An organic EL display according to claim 12, wherein said plurality of reflective, transmissive or semi-transmissive film includes an organic EL electrode.

[Claim 14] An organic EL display with a laminated optical structure with low reflectivity and transmissivity including a first semi-transmissive film, a second semi-transmissive film and a reflective film stacked on a substrate in this order or an order opposite thereto, wherein said laminated optical structure with low reflectivity and transmissivity is an organic EL device.

[Claim 15] An organic EL display according to claim 14, wherein said first semi-transmissive film and said reflective film are electrodes, and said second semi-transmissive film is an organic EL layer having at least a light emitting layer.

[Claim 16] An organic EL display comprising a structure with low reflectivity and transmissivity composed of at least two layers, and an organic EL device having an organic EL layer composed of at least a light emitting layer and a transporting layer for transporting charges to said light emitting layer, said organic EL layer being sandwiched between two electrodes,

wherein said structure with low reflectivity and transmissivity includes said transferring layer.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

This invention relates to an organic electroluminescence (EL) device.

[0002]

[Prior Art]

Generally, the organic EL device has a structure with an organic material laminate sandwiched between a transparent conductive film and a metallic electrode. The EL light emitted within the device is extracted externally from the device through a transparent electrode.

[0003]

The rear electrode arranged on the side of light extraction side, i.e. on the side opposite to a viewer is made of an alloy of Mg and Ag, an alloy of Al and Li, etc. These metals, which have reflectivity, strongly reflects the external light which is incident from the outside. The display thus obtained is largely influenced by the external light reflected at the rear electrode, and provides poor visibility like a mirror face when seen from a viewer.

[0004]

In order to avoid such inconvenience, for the purpose

of blocking the reflection of the external light, generally, an expensive circularly-polarizing filter is attached to the exterior of the device. However, in a "top emission structure" in which a light extracting electrode is arranged on an organic film but not on the side of a substrate, it is difficult to provide the circularly-polarizing filter so that it is in contact with the exterior of the device.

[0005]

Even where the light extracting electrode is arranged on the side of the substrate, if the substrate itself is made thin, the thickness of the circularly-polarizing filter hinders low-profiling and weight reduction. Further, the transmissivity of the circularly-polarizing filter is about 40 % so that the using efficiency of the organic EL light is half or less the case with no filter.

[0006]

Another known technique for preventing reduction in the visibility is to make the rear surface of the device non-reflective. A known method of making a non-reflective electrode is to use an absorbent material as an electrode. Patent No. 2529741 discloses a method for manufacturing a device with low reflectivity having a rear electrode in a laminated structure as shown in Fig. 4 using optical interference.

[0007]

Still another known technique for preventing the

reduction in the visibility is to make both electrodes transmissive or semi-transmissive and arrange a non-reflective film outside either electrode to suppress the reflection of external light at the rear electrode, thereby improving visibility.

[0008]

[Problems that the Invention is to Solve]

These devices, in which the rear surface of the device is made lowly-reflective or non-reflective to improve visibility without providing a circularly-polarizing filter, provide an abrupt reduction in the efficiency of externally extracting light from the device.

[0009]

The internally emitted light in the organic EL device is radiated with equal intensities in all the directions as shown in Fig. 1. Therefore, the light with the intensity equal to that radiated forward is also radiated in the rear direction. The light which is actually externally extracted from the device is the sum of electric field amplitudes of forward radiated light and the light which is radiated in the rear direction, reflected form the rear electrode and returns forward. Generally, in the organic EL device, the thickness of an optical film in a laminated device structure is optimized so that the phase difference between the forward radiated light and the reflected light of the rearward radiated light satisfies the

condition of mutual intensifying of optical interference, thereby effectively externally extracting the light multiply reflected from the rear electrode and other reflecting planes as outside EL light.

[0010]

On the other hand, when the non-reflective electrode is used as the rear electrode, the EL light radiated to the rear side is not extracted on the front side. As a result, the intensity of the organic EL light thus externally extracted is supposedly about 1/2 of that of the entire EL light.

[0011]

However, the actual experiment shows that the intensity of the organic EL light externally extracted has been reduced to about 1/4 in the device equipped with the non-reflective electrode as compared with the ordinary EL device. This means that the using efficiency is referred to about half of that of ordinary device equipped with the circularly-polarizing filter.

[0012]

In a field of an organic EL device using the light extracted to at least the one side, this invention provides a method of improving the intensity of externally extracted EL light when using the technique of improving the visibility of the display by reducing the reflectivity on a rear side and an organic EL display using such a technique.

[0013]

[Means for Solving the Problems]

The invention described in claim 1 is an organic EL display equipped with an organic EL device with an organic material sandwiched by at least two electrodes, comprising: a light emitting layer which emitting light; a front reflecting area arranged on the side of a viewer with respect to the light emitting layer; and a rear reflecting portion arranged on the side opposite to the viewer with respect to the light emitting layer, wherein the optical film thickness of the organic material, intensity reflectivity R_1 at the front reflecting area and intensity reflectivity R_2 at the front reflecting area are adjusted so that the external light intensity reflectivity of the display viewed from the viewer is 10 % or less by an optical interference effect.

[0014]

[Mode for Carrying Out the Invention]

The inventors of this invention, on a basis of an experiment, have found that when the reflectivity at the rear electrode of the organic EL device is reduced to zero, the efficiency of externally extracting the EL light from the device is reduced to approximately 1/4 and when it is left effectively, the efficiency can be improved.

[0015]

The inventors of this invention investigated, on a basis

of interference model, the EL light (beam) emitted internally within a device and reflected light beam of external light which is incident from the outside of the device and reflected to the outside again, and found that both light beams are correlated with the reflectivity and transmissivity of each of two areas sandwiching an EL light-emitting layer within the device and an optical distance within the device.

[0016]

The inventors found that there is a range of the reflectivity and transmissivity of each of the two areas sandwiching the above light emitting layer which can improve the efficiency of externally extracting the EL light while maintaining the reflectivity of the external light at a low value, using that a difference exists between the equation representative of the efficiency of extracting the EL light and that representative of the reflectivity of the external light.

[0017]

Now referring to the drawings, a detailed explanation will be given of an organic EL display.

[0018]

Fig. 1 is a view showing a sectional structure of the organic EL device in an organic EL display and a distribution of the intensity of the EL light emitted internally within the organic EL device. The organic EL light device includes a

transparent electrode 2 which serves as an anode arranged on a glass substrate 1, a rear electrode 3 which serves as a cathode and an organic layer 4 which is sandwiched between the transparent electrode 2 and the rear electrode 3.

A viewer 7 sees the EL light 8 which is radiated externally from the device through the transparent electrode 2.

[0019]

The organic layer 4 is made by heating and evaporating a plurality of organic materials within a vacuum bath after the transparent electrode 2 deposited on the glass substrate 1 has been subjected to necessary steps such as patterning. After a hole transporting layer 4a having a thickness of several tens to several hundreds nm has been deposited on the transparent electrode 2, a light emitting layer 5 is deposited thereon and an electron transporting layer 4b is further deposited thereon. As the case may be, one of these layers has plural functions. The laminated structure of a plurality of materials may have a single function. The above technique is directed to the method of depositing low-molecular organic EL materials. But, solutions of polymer organic EL materials may be applied successively using the technique of spin-coating or ink jetting. The deposition of the rear electrode 3 is a final step of the deposition and required to minimize the damage to the organic layer 4 previously deposited. For this purpose, in many cases, metal is heated and evaporated in vacuum.

[0020]

The organic EL device consisting of a plurality of layers stacked successively behaves as a pn-junction type semiconductor light-emitting diode. Specifically, when a voltage is applied between the transparent electrode 2 and the rear electrode 3, holes are injected from the transparent electrode 2 serving as an anode and electrons are injected from the rear electrode 3 serving as a cathode. The holes are transported through the hole transporting layer 4a and the electrons are transported through the electron transporting layer 4b. Both carriers are re-combined within the light emitting layer 5. The energy thus generated excites the molecules within the light emitting layer so that when the excited molecules return to their ground state, fluorescence or phosphorescence is emitted.

[0021]

Actually, because of the difference in the energy level at the interfaces among the hole transporting layer 4a, light-emitting layer 5 and electron transporting layer 4b, the carriers are concentrated to the interfaces. In most devices, the carrier recombination occurs intensively at either interface of the light emitting layer 5. Therefore, as seen from Fig. 1, it is known that the intensity of the EL light within the device has an abrupt peak in the vicinity of the interface of the light emitting layer 5, and is distributed

so as to decrease exponentially toward the inside of the light emitting layer.

[0022]

It is supposed that the distance until the peak of the intensity decreases to 1/e is 5 - 20 nm. Most of EL light emitting points 6 center on the vicinity of the interface to constitute a layer.

[0023]

Fig. 2 is a view for explaining the optical interference within the device of the light radiated from the EL light emitting point 6. The EL light radiated from the EL light emitting points 6 is isometric and non-polarized, and is also radiated toward the rear electrode with the intensity equal to that radiated toward the viewer 7. Each of the EL light emitting points 6 which center on the interface of the light emitting layer 5 radiates electromagnetic waves which are not correlated with one another. The electromagnetic waves which are not correlated with one another are difficult to interfere with one another. However, in the organic EL device, strong interference occurs for the following reason.

[0024]

Generally, the fluorescent life of an organic molecule is several nano seconds. Its propagating distance for this time is several tens of cms in vacuum. Generally, the distance between the light emitting points 6 and the rear electrode 3

which is reflective is several tens to several hundreds of nms, and the refractive index of the organic material 4 is about 1.6 to 2. For this reason, the traveling distance of the light reflected from the rear electrode 3 is sufficiently shorter than the coherence length.

[0025]

Therefore, when the light radiated by the single light emitting point 6 is reflected by the rear electrode 3 to return to the light emitting point 6 again, the light emitting point 6 is continuing to radiate the electro-magnetic wave correlated with the reflected light. Each of all the light emitting points brings about the interference phenomenon due to its own reflected light. The synthesized wave thus obtained is observed as the EL light. As a result, the EL light internally emitted is affected by the self-interference phenomenon.

[0026]

Fig. 3 is a view showing the method for optically optimizing the organic EL device structure. In order to increase the light 8 extracted externally from the device using the optical interference within the device, the thickness of each of the layers 4a, 5 and 4b constituting the organic material 4 is adjusted so that all the waves shown in Fig. 3 are in phase.

[0027]

More specifically, the optical distance 10a between the light emitting interface 5a and the rear reflecting plane 11

is adjusted so that first forward radiated light 9a and first rearward reflected light 9b are in phase. Namely, the optical distance 10a may be adjusted so that a phase difference is integer times of 2 π between the round stroke where the first rearward reflected light 9b travels and the single reflection stoke on the rear reflecting plane 11.

[0028]

Likewise, the optical distance 10b between the light emitting interface 5a and the front reflecting plane 12 is adjusted so that first forward radiated light 9a and first front reflected light 9c are in phase. At this time, the first forward reflected light 9c is first reflected from the front reflecting plane 12, successively reflected by the rear reflecting plane 11 and thereafter interferers with the first front radiated light 9a.

[0029]

Assuming that the distance 10a between the light emitting interface 5a and the rear reflecting plane 11 is adjusted as described above, as long as the reflected light 9d on the front reflecting plane of the first forward reflected light and the first rearward radiated light 9e are in phase, the first front radiated light 9a and the first front reflected light 9c are automatically in phase. Namely, the optical distance 10b may be adjusted so that a phase difference is integer times of 2 π between the round stroke where the reflected light 9d on the

front reflecting plane of the first forward reflected light travels and the single reflection stroke on the front reflecting plane 12.

[0030]

In the device with the optical distances 10a and 10b thus adjusted, the entire light internally emitted within the device shown in Fig. 3 is intensified in the same phase. It will be understood that on the basis of the light emitting theory of the device, the process of injection, transportation and recombination of the carriers does not vary according to the thickness of the layers constituting the device and the distribution of the intensity of the emitted light within the device and the intensity itself are maintained. In other words, even with such adjustment of the optical film thickness, the intensity of the emitted light when the same current is passes through the device is always the same.

[0031]

In the organic EL display according to this embodiment, the optical film thickness of the organic layer 4, the light intensity reflectivity R1 at the area from which the light nearer than the light emitting layer 5 to a viewer is reflected and the light intensity reflectivity R2 at the area from which the light farther than the light emitting layer 5 from the viewer is reflected are adjusted so that the external light intensity of the organic EL display becomes 10 % or less owing to the

optical interference effect. The reason will be explained as follows.

[0032]

The inventors of this invention attempted an experiment of making the rear electrode 3 non-reflective in Fig. 1. In this experiment using the technique described in Patent No. 2529741, the non-reflective electrode using the optical interference.

[0033]

Example 1

The technique described in Patent No. 2529741 is as follows. As seen from Fig. 4, on a glass substrate 13, a structure is made in which a second semi-transparent layer 15 is sandwiched between a first semi-transparent layer 14 and a highly reflective layer 16.

[0034]

In this case, the reflectivity and transmissivity of the first semi-transparent layer 14, the thickness of the second semi-transparent layer 15 and the reflectivity of the highly reflective layer 16 are adjusted so that the reflected light 18a from the first semi-transparent layer 14 and the reflected light 18b from the highly-reflective layer 16 cancel each other, thereby making a non-reflective laminated structure. In a simple case, the second semi-transparent layer 15 may have an optical thickness of about $1/4\lambda$ of an objective wavelength.

[0035]

For example, the first semi-transmissive layer 14 and highly reflective layer 16 may be made of a metallic aluminum film. The second semi-transmissive layer 15 can be made of a semi-transparent organic evaporated film. In addition, the second semi-transmissive layer 15 may be made of aluminum quinolinol complex (Alq_3) as an organic EL material. The refractive index of Alq_3 can be measured by e.g. ellipsometry technique and is 1.76 at a wavelength of 525 nm.

[0036]

Assuming that the refractive index is n, and the thickness is d, the optical thickness is represented by n x d. In the case of the Alq_3 film, d which is 1/4 of $\lambda = 525$ nm can be calculated as follows.

[0037]

$$n \bullet d = 525/4 = 131.25$$

$$\therefore\ d = 74.6\ \text{nm}$$

[0038]

The reflectivity was measured from the side of the glass on the structure in which a very thin aluminum as the first semi-transmissive layer 14 is deposited on the glass substrate 13 by heating in vacuum, the Alq_3 film having a thickness of 80 nm as the second semi-transmissive layer 15 is deposited by heating in vacuum, and an aluminum film having a thickness of 100 nm as the highly reflective layer 16 is vacuum-deposited.

The measurement result is shown in Fig. 5. It can be seen that the reflectivity can be reduced to 1 % at the lowest.

[0039]

Further, as shown in Fig. 5, the lowest reflectivity can be adjusted by adjusting the thickness of the Alq_3 film as the second semi-transmissive layer 15. The reflectivity can also be adjusted by varying the thickness of the thin aluminum film as the first semi-transmissive layer.

[0040]

The non-reflective laminated structure thus obtained was used as a cathode of the organic EL device. The transparent electrode deposited on soda lime glass was patterned and the organic EL device was made thereon. A copper phthalocyanine film having a thickness of 25 nm as the hole injecting layer, an α-NPD film having a thickness of 45 nm as the hole transporting film and the Alq_3 film having a thickness of 60 nm as the light emitting layer were successively vacuum-deposited. The film thickness of each layer was selected in the combination which gives the maximum outside EL light intensity by the experiment for the optimum designing as shown in Fig. 3. Thereafter, after an Li_2O film having a thickness of 0.3 nm as an electron injecting additive has been deposited, the organic EL device was manufactured which has the non-reflective laminated structure with the above thin aluminum, Alq_3 80 nm thick and highly reflective aluminum deposited.

[0041]

Example 2

In comparison to the above organic EL device, likewise, on the soda lime glass equipped with ITO, copper phthalocyanine 25 nm thick, α-NPD 45 nm thick and Alq_3 60 nm thick were successively vacuum-deposited. After Li_2O 0.3 nm thick as an electron injecting additive has been deposited, the organic EL device was manufactured which does not have the non-reflective laminated structure with aluminum 100 nm thick deposited.

[0042]

Fig. 6 is a graph showing the voltage-current characteristic of each of the organic EL device having the non-reflective laminated structure (Example 1) and organic EL device with no non-reflective laminated structure (Example 2). As can be seen from Fig. 6, the voltage-current characteristics in both devices are almost the same. Therefore, it can be supposed that in both devices, the organic diode equally functions and the internal light-emitting intensities for the same current are equal.

[0043]

On the other hand, Fig. 7 is a graph showing the current-brightness characteristic in Examples 1 and 2. As can be seen from Fig. 7, in all the current ranges, the current-brightness efficiency in Example 1 is always about 1/4 of that in Example 2.

[0044]

As understood from the above description, the organic EL device in Example 2 is designed so that the rearward radiated light intensifies the forward light using the reflection/interference phenomenon. On the other hand, in the organic EL device in Example 1, because the rearward reflected light is not reflected forward, the intensity of the extracted light is supposedly about 1/2. However, a simple model calculation shows that the intensity is not 1/2, but about 1/4.

[0045]

This can be explained with reference to the following interference model within the organic EL device. First, optical interference phenomenon must be analyzed taking an incident angle of light into consideration. The following explanation will be limited to the case of vertical incidence. If the incidence angle is not vertical, the phase and reflection intensity vary according to the incidence angle, but great importance may be given to the vertical incidence. Further, as regards the polarization of light, because the EL radiated light is non-polarized, and distinction in the polarization in the case of vertical incidence is not required, the polarization of light will be also disregarded hereafter.

[0046]

In the multiple interference in the optical film, the phase delay or attenuation due to absorption in the multiple

reflection and propagation must be taken into consideration. However, as long as the organic EL device is optimized so that all the reflected beams of light are in phase as in Example 1, all the beams of light externally extracted from the device can be regarded to be in the same phase, and therefore, the term of the phase will be omitted in the following explanation.

[0047]

Further, where these optical interferences are explained quantitatively, after all the superpositions of the electromagnetic waves have been considered, finally, the square of the absolute value must be taken as the intensity of light. Specifically, the intensity, reflectivity, transmissivity, etc. to be measured are represented by the square of amplitude of the electric field of a light wave. Actually, the electromagnetic wave is represented by a complex number, and its square of the absolute value represents the intensity of light. However, for simplicity of explanation, the explanation will be made in the region of real numbers since its generality is not lost.

[0048]

In M. Borun, E. Wolf, "Theory of Optics I" TOKAI UNIVERSITY PUBLISHER, 1974, pages 61-73, the formulas of Fresnel on the reflection/refraction phenomenon is described.

For example, the reflectivity R measured on a certain reflecting plane denotes the reflectivity of the intensity of

light and is related with a electric-field amplitude reflectivity r as follows.

[0049]

$$R = |r|^2 \quad \dots (1)$$

$$\therefore\ r = \sqrt{(|R|)} \quad \dots (2)$$

[0050]

This relationship also holds for complex reflectivity. In the following explanation, it is assumed that the intensity reflectivity and intensity transmissivity are denoted by capital letters R and T, and the electric-field amplitude reflectivity and electric-field amplitude transmissivity are denoted by small letters r and t.

[0051]

As described in "Theory of Optics I", the electric-field amplitude reflectivity r and electric-field amplitude transmissivity t of the light which is incident from the medium with refractivity n_1 to the medium with refractivity with n_2 are expressed as follows.

[0052]

$$r = (n_2 - n_1)/(n_2 + n_1) \quad \dots (3)$$

$$t = 2\bullet n_2/(n_2 + n_1) \quad \dots (4)$$

[0053]

As regards the same media, conversely, where the light is incident from the medium with n_2 to the medium with n_1, the electric-field amplitude reflectivity r′ and electric-field

amplitude transmissivity t′ are expressed as follows.

[0054]

$$r' = (n_1 - n_2)/(n_2 + n_1) = -r \quad \dots (5)$$

$$t' = 2 \bullet n_1/(n_2 + n_1) \quad \dots (6)$$

[0055]

The corresponding intensity reflectivity R, R′ and intensity transmissivity T, T′ are expressed as follows.

[0056]

$$R = |r|^2 = r^2$$

$$= (n_2 - n_1)^2/(n_1 + n_2)^2 = R' \quad \dots (7)$$

$$T = (n_2/n_1) \bullet |t|^2$$

$$= 4 \bullet n_1 \bullet n_2/(n_2 + n_1)^2 = T'$$

$$= t \bullet t' \quad \dots (8)$$

[0057]

The following relationship also holds.

[0058]

$$r + t = 1$$

$$r^2 + t^2 = 1$$

[0059]

On the basis of the above relationships described above, an explanation will be given of the optical model of an organic EL display.

Fig. 8 is a conceptual view of the optical model of the organic EL display. All the organic EL devices can be simplified optically as illustrated in Fig. 8.

[0060]

Fig. 3 is a specific case of the case shown in Fig. 8. Fig. 3 shows the case where the reflectivity r_2 on the rear reflecting plane 11 is as high as $r_2 \approx 1$ and the reflectivity r_1 on the front reflecting plane 12 is $r_1 \ll 1$. The intensity of the light when reflection is repeated twice or more on the front reflecting plane 12 is negligibly small. Therefore, only the four optical waves 9a, 9b, 9c and 9d within the device have only to be considered.

[0061]

Fig. 9 is a view illustrating the multiple reflection of the light radiated internally in the device and the electric-field amplitude of the light externally extracted from the device in the configuration of Fig. 8. With the electric-field amplitude of the internally emitted light being E, the electric-field amplitude of each of the light waves is written.

[0062]

The ratio of the amplitude of the synthesized wave of the light waves externally extracted to the electric-field amplitude E of the internally emitted light is referred to as the synthesized electric-field amplitude transmissivity m_{EL} of the extracted EL light.

Since all the light beams extracted externally have been adjusted to be in phase, simple addition thereof may be made.

Thus, the m_{EL} of the light wave extracted on the side of a viewer 7 can be expressed as follows.

[0063]

[Equation 2]

$$\begin{aligned} m_{EL} &= t_1\{1 + r_2 + r_1r_2 + r_1r_2^2 + r_1^2r_2^2 + \cdots\} \\ &= t_1\{(1 + r_1r_2 + r_1^2r_2^2 + \cdots) + r_2(1 + r_1r_2 + r_1^2r_2^2 + \cdots)\} \\ &= t_1\left\{(1 + r_2)\sum_{k=0}^{\infty}(r_1r_2)^k\right\} = \frac{1+r_2}{1-r_1r_2}t_1 \end{aligned} \quad \ldots (9)$$

[0064]

In this case, $0 \leq |r_1\ r_2| \leq 1$ led from $0 \leq r_1 \leq 1$ and $0 \leq r_2 \leq 1$ and the following formulas have been employed.

[0065]

[Equation 3]

$$\lim_{n\to\infty}\sum_{k=0}^{n} p^k = \lim_{n\to\infty}\frac{1-p^{n+1}}{1-p} = \frac{1}{1-p} \qquad \textit{wherein} \quad (0 < p < 1) \quad \ldots (10)$$

[0066]

Likewise, the synthesized electric-field transmissivity m_{EL} of the EL light extracted on the side opposite to a viewer 7 can be expressed as follows.

[0067]

[Equation 4]

$$\begin{aligned} m_{EL} &= t_2\{1 + r_1 + r_1 r_2 + r_1^2 r_2 + r_1^2 r_2^2 + \cdots\} \\ &= t_2\{(1 + r_1 r_2 + r_1^2 r_2^2 + \cdots) + r_1(1 + r_1 r_2 + r_1^2 r_2^2 + \cdots)\} \\ &= t_2\left\{(1 + r_1)\sum_{k=0}^{\infty}(r_1 r_2)^k\right\} = \frac{1 + r_1}{1 - r_1 r_2} t_2 \end{aligned} \qquad \cdots \quad (11)$$

[0068]

Fig. 10 is a conceptual view of the multiple interference phenomenon in the organic EL device regarding incident external light 22a. The light on the side of the viewer 7 includes a first reflected light beam 22b and synthesized light beams 23 which are incident to and permeate through the inside of the device and emerges externally from the device while repeating the multiple reflections. In the device in which the multiple-reflected light beams of the EL light emitted internally are adjusted to be in phase, all the synthesized light beams 23 are automatically in phase.

[0069]

On the other hand, from the Fresnel formulas, the first reflected light beam 22b provides the reflectivity r1′ with an inverted sign according to the relationship of refractivity of the medium between the incident side and the penetrating side. This means that the phase is shifted by π. Incidentally, the incident light beam 22a and permeating light beam 22c are always in phase.

[0070]

Figs. 11(a) and 11(b) views showing the inverting status of the phase of the light beam. The case where the phase is

inverted is denoted by − 1, whereas the case whereas the phase is not inverted is denoted by 1. Since $r = -r'$, when the reflection accompanying phase inversion occurs in a certain incidence direction, in the light incidence in the opposite direction, the phase is not inverted.

[0071]

Fig. 11(a) is directed to the case where at the first reflection of the external light, its phase is inverted. In this case, the light within the device is reflected in phase on the front reflecting area 20. Specifically, the light which travels back and forth once between the front reflecting area 20 and a rear reflecting area 19 is adjusted to provide a phase difference of $2m\pi$ (m denotes a natural number) through propagation/reflection. This adjustment is identical to the optimizing of the device as explained already. The device adjusted so as to intensify the EL light is automatically adjusted in this manner.

[0072]

Fig. 11(b) is directed to the case where at the first reflection of the external light, its phase is not inverted. In this case, the light within the device is reflected in an opposite phase on the front reflecting area 20. Specifically, the light which travels back and forth once between the front reflecting area 20 and a rear reflecting area 19 is adjusted to provide a phase difference of $2(m-1)\pi$ (m denotes a natural

number) through propagation/reflection. This adjustment is identical to the optimizing of the device as explained already. The device adjusted so as to intensify the EL light is automatically adjusted in this manner.

[0073]

In this way, in the optimized EL device, in any case, in the first reflected light beam 22b and the penetrated synthesized light beams 23 in Fig. 10 are out of phase. Now, the synthesized amplitudes of the penetrated synthesized light beams 23 can be expressed as follows.

[0074]

$$t_1 t_2' r_2 (1 + r_1 r_2 + (r_1 r_2)^2 + \ldots) = t_1 t_1' r_2 / (1 - r_1 r_2) \quad \ldots \quad (12)$$

[0075]

From this equation, the external light synthesized amplitude reflectivity $m_{external\ light}$ which represents the ratio of the electric field amplitude of all the synthesized light waves in Fig. 10 to the electric-field amplitude A of the incident external light 22a can be expressed as follows.

[0076]

$$m_{external\ light} = |r_1'| - |tt' r_2 / (1 - r_1 r_2)| \quad \ldots \quad (13)$$

[0077]

Using the equation $t_1 t_1' = T_1 = 1 - r_1^2$, $|r_1'| = |r_1|$, Equation (13) can be rewritten.

[0078]

$$m_{external\ light} = |r_1'| - |r_2| (1 - |r_1|^2) / (1 - |r_1 r_2|)$$

$$=(|r_1 - r_2|)/(1-|r_1 r_2|) \quad \ldots (14)$$

[0079]

The explanation made hitherto is the general optical mode analysis of the organic EL device. In summary, using the reflectivities r_1 and r_1' and transmissivities t_1, t_1' on the front reflecting area and the reflectivity r_2 on the rear reflecting area, assuming that the electric-field amplitude of the internal EL light is E and the electric-field amplitude of the incident light is A, the electric-field amplitude E_{out} of the EL light externally extracted and the electric-field amplitude A_{REF} of the incident external light reflected externally can be expressed as follows.

[0080]

[Equation 5]

$$E_{out} = m_{EL} \cdot E = \frac{1+r_2}{1-r_1 r_2} t_1 \cdot E \quad \ldots (15)$$

[0081]

[Equation 6]

$$A_{REF} = m_{EXT} \cdot A = \frac{|r_1 - r_2|}{1-|r_1 r_2|} \cdot A \quad \ldots (16)$$

[0082]

In this case, the optical intensity I_{OUT} and I_{REF} can be expressed by the square of the E_{OUT} and A_{REF}. Particularly, the

condition that

$A_{REF} = 0$ is $r_1 = r_2$.

[0083]

Regarding Equation (15), the calculation result of the intensity ratio $M_{EL} = I_{OUT}/E^2$ in the range in which r_1 and r_2 are 0 to 0.95, respectively is shown in Table 1. Table 1 shows that the intensity reflectivity $M_{EL} = 1$ on the columns on the diagonal line satisfying $r_1 = r_2$.

[0084]

[Table 1]

EL Light Apparent Intensity Transmissivity M_EL

		r_1																			
		0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
	0.00	1.00	0.90	0.81	0.72	0.64	0.56	0.49	0.42	0.36	0.30	0.25	0.20	0.16	0.12	0.09	0.06	0.04	0.04	0.01	0.00
	0.05	1.10	1.00	0.90	0.81	0.72	0.64	0.56	0.48	0.41	0.35	0.29	0.24	0.19	0.14	0.11	0.07	0.05	0.05	0.01	0.00
	0.10	1.21	1.10	1.00	0.90	0.81	0.72	0.63	0.55	0.47	0.40	0.34	0.27	0.22	0.17	0.13	0.09	0.06	0.06	0.01	0.00
	0.15	1.32	1.21	1.10	1.00	0.90	0.80	0.71	0.62	0.54	0.46	0.39	0.32	0.26	0.20	0.15	0.10	0.07	0.07	0.02	0.00
	0.20	1.44	1.33	1.21	1.11	1.00	0.90	0.80	0.70	0.61	0.53	0.44	0.37	0.30	0.23	0.18	0.12	0.08	0.08	0.02	0.01
	0.25	1.56	1.45	1.33	1.22	1.11	1.00	0.89	0.79	0.69	0.60	0.51	0.43	0.35	0.27	0.21	0.15	0.10	0.10	0.03	0.01
	0.30	1.69	1.57	1.45	1.34	1.22	1.11	1.00	0.89	0.79	0.68	0.58	0.49	0.40	0.32	0.24	0.18	0.12	0.12	0.03	0.01
	0.35	1.82	1.70	1.59	1.47	1.35	1.23	1.11	1.00	0.89	0.78	0.67	0.57	0.47	0.37	0.29	0.21	0.14	0.14	0.04	0.01
	0.40	1.96	1.84	1.72	1.60	1.48	1.36	1.24	1.12	1.00	0.88	0.77	0.65	0.54	0.44	0.34	0.25	0.17	0.17	0.05	0.01
r_2	0.45	2.10	1.99	1.87	1.75	1.62	1.50	1.38	1.25	1.13	1.00	0.88	0.75	0.63	0.51	0.40	0.30	0.21	0.21	0.06	0.02
	0.50	2.25	2.14	2.02	1.90	1.78	1.65	1.53	1.40	1.27	1.13	1.00	0.87	0.73	0.60	0.48	0.36	0.25	0.25	0.07	0.02
	0.55	2.40	2.29	2.18	2.06	1.94	1.82	1.69	1.56	1.42	1.28	1.14	1.00	0.86	0.71	0.57	0.44	0.31	0.31	0.09	0.03
	0.60	2.56	2.46	2.35	2.23	2.12	1.99	1.87	1.73	1.60	1.45	1.31	1.15	1.00	0.84	0.68	0.53	0.38	0.38	0.12	0.03
	0.65	2.72	2.62	2.52	2.41	2.30	2.18	2.06	1.93	1.79	1.65	1.49	1.34	1.17	1.00	0.82	0.65	0.47	0.47	0.16	0.05
	0.70	2.89	2.80	2.71	2.61	2.50	2.39	2.27	2.14	2.01	1.86	1.71	1.55	1.37	1.19	1.00	0.80	0.60	0.60	0.21	0.06
	0.75	3.06	2.98	2.90	2.81	2.71	2.61	2.50	2.38	2.25	2.11	1.96	1.80	1.62	1.43	1.22	1.00	0.77	0.77	0.29	0.09
	0.80	3.24	3.17	3.10	3.02	2.94	2.85	2.75	2.64	2.52	2.39	2.25	2.09	1.92	1.72	1.51	1.27	1.00	1.00	0.41	0.14
	0.85	3.42	3.37	3.31	3.25	3.18	3.10	3.02	2.93	2.83	2.72	2.59	2.44	2.28	2.09	1.88	1.63	1.34	1.34	0.62	0.23
	0.90	3.61	3.57	3.53	3.49	3.44	3.38	3.32	3.25	3.17	3.08	2.98	2.87	2.73	2.57	2.37	2.14	1.84	1.84	1.00	0.43
	0.95	3.80	3.78	3.76	3.74	3.71	3.68	3.64	3.61	3.56	3.51	3.45	3.38	3.29	3.18	3.05	2.88	2.64	2.64	1.81	1.00

[0085]

Further, regarding Equation (16), the calculation result of the intensity ratio $M_{EXTERNAL\ LIGHT} = I_{REF}/A^2$ in the range in which r_1 and r_2 are 0 to 0.95, respectively is shown in Table 2. Table 2 shows that the intensity reflectivity $M_{EXTERNAL\ LIGHT} = 0$ on the columns on the diagonal line satisfying $r_1 = r_2$.

[0086]

[Table 2]

External light Apparent Intensity Reflectivity M_External light

		r_1																			
		0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
r_2	0.00	0.0%	0.3%	1.0%	2.3%	4.0%	6.3%	9.0%	12.3%	16.0%	20.3%	25.0%	30.3%	36.0%	42.3%	49.0%	56.3%	64.0%	72.3%	81.0%	90.3%
	0.05	0.3%	0.0%	0.3%	1.0%	2.3%	4.1%	6.4%	9.3%	12.8%	16.7%	21.3%	26.4%	32.2%	38.5%	45.4%	52.9%	61.0%	69.8%	79.2%	89.3%
	0.10	1.0%	0.3%	0.0%	0.3%	1.0%	2.4%	4.3%	6.7%	9.8%	13.4%	17.7%	22.7%	28.3%	34.6%	41.6%	49.4%	57.9%	67.2%	77.3%	88.2%
	0.15	2.3%	1.0%	0.3%	0.0%	0.3%	1.1%	2.5%	4.5%	7.1%	10.4%	14.3%	19.0%	24.5%	30.7%	37.8%	45.7%	54.6%	64.4%	75.2%	87.0%
	0.20	4.0%	2.3%	1.0%	0.3%	0.0%	0.3%	1.1%	2.6%	4.7%	7.5%	11.1%	15.5%	20.7%	26.8%	33.8%	41.9%	51.0%	61.3%	72.9%	85.7%
	0.25	6.3%	4.1%	2.4%	1.1%	0.3%	0.0%	0.3%	1.2%	2.8%	5.1%	8.2%	12.1%	17.0%	22.8%	29.8%	37.9%	47.3%	58.0%	70.3%	84.3%
	0.30	9.0%	6.4%	4.3%	2.5%	1.1%	0.3%	0.0%	0.3%	1.3%	3.0%	5.5%	9.0%	13.4%	18.9%	25.6%	33.7%	43.3%	54.5%	67.6%	82.6%
	0.35	12.3%	9.3%	6.7%	4.5%	2.6%	1.2%	0.3%	0.0%	0.3%	1.4%	3.3%	6.1%	10.0%	15.1%	21.5%	29.4%	39.1%	50.7%	64.5%	80.8%
	0.40	16.0%	12.8%	9.8%	7.1%	4.7%	2.8%	1.3%	0.3%	0.0%	0.4%	1.6%	3.7%	6.9%	11.4%	17.4%	25.0%	34.6%	46.5%	61.0%	78.7%
	0.45	20.3%	16.7%	13.4%	10.4%	7.5%	5.1%	3.0%	1.4%	0.4%	0.0%	0.4%	1.8%	4.2%	8.0%	13.3%	20.5%	29.9%	42.0%	57.2%	76.3%
	0.50	25.0%	21.3%	17.7%	14.3%	11.1%	8.2%	5.5%	3.3%	1.6%	0.4%	0.0%	0.5%	2.0%	4.9%	9.5%	16.0%	25.0%	37.1%	52.9%	73.5%
	0.55	30.3%	26.4%	22.7%	19.0%	15.5%	12.1%	9.0%	6.1%	3.7%	1.8%	0.5%	0.0%	0.6%	2.4%	5.9%	11.6%	19.9%	31.7%	48.0%	70.2%
	0.60	36.0%	32.2%	28.3%	24.5%	20.7%	17.0%	13.4%	10.0%	6.9%	4.2%	2.0%	0.6%	0.0%	0.7%	3.0%	7.4%	14.8%	26.0%	42.5%	66.3%
	0.65	42.3%	38.5%	34.6%	30.7%	26.8%	22.8%	18.9%	15.1%	11.4%	8.0%	4.9%	2.4%	0.7%	0.0%	0.8%	3.8%	9.8%	20.0%	36.3%	61.5%
	0.70	49.0%	45.4%	41.6%	37.8%	33.8%	29.8%	25.6%	21.5%	17.4%	13.3%	9.5%	5.9%	3.0%	0.8%	0.0%	1.1%	5.2%	13.7%	29.2%	55.7%
	0.75	56.3%	52.9%	49.4%	45.7%	41.9%	37.9%	33.7%	29.4%	25.0%	20.5%	16.0%	11.6%	7.4%	3.8%	1.1%	0.0%	1.6%	7.6%	21.3%	48.4%
	0.80	64.0%	61.0%	57.9%	54.6%	51.0%	47.3%	43.3%	39.1%	34.6%	29.9%	25.0%	19.9%	14.8%	9.8%	5.2%	1.6%	0.0%	2.4%	12.8%	39.1%
	0.85	72.3%	69.8%	67.2%	64.4%	61.3%	58.0%	54.5%	50.7%	46.5%	42.0%	37.1%	31.7%	26.0%	20.0%	13.7%	7.6%	2.4%	0.0%	4.5%	27.0%
	0.90	81.0%	79.2%	77.3%	75.2%	72.9%	70.3%	67.6%	64.5%	61.0%	57.2%	52.9%	48.0%	42.5%	36.3%	29.2%	21.3%	12.8%	4.5%	0.0%	11.9%
	0.95	90.3%	89.3%	88.2%	87.0%	85.7%	84.3%	82.6%	80.8%	78.7%	76.3%	73.5%	70.2%	66.3%	61.5%	55.7%	48.4%	39.1%	27.0%	11.9%	0.0%

[0087]

These results will be applied to Examples 1 and 2. In Example 2, the front reflecting area reflectivity r_1 can be estimated as follows. In Example 2, the planes which can be a highly reflective front plane are organic material/ITO/glass interfaces. Particularly, since there is a large difference in the refractivity at the ITO/glass interface whereas there is a small difference in the refractivity at the organic material/ITO interface, the ITO/glass interface can be the front reflecting area. This has been verified experimentally. Therefore, it is right that the maximum EL light extracting

efficiency is obtained when the distance between the interface and light emitting layer is adjusted to intensify the EL light optically.

[0088]

The electric-field amplitude reflectivity r_1 at the interface between ITO (refractivity n =1.93) and glass (refractivity n = 1.52) is expressed as follows.

[0089]

$$\begin{aligned} r_2 &= (n_{ITO} - n_{glass}) / (n_{ITO} + n_{glass}) \\ &= (1.93 - 1.52) / (1.93 + 1.52) \\ &= 0.119 \qquad \ldots (17) \end{aligned}$$

[0090]

Since the reflection/transmission phenomenon with no absorption is at issue, it can be assumed that $t_1 = 1 - r_1$.

[0091]

The rear reflecting area is the interface between the aluminum, which serves as the metallic electrode and the organic material. Since the electric-field amplitude reflectivity at the Alq/Al interface is 92.5 %, if $(r_1, r_2) = (0.119, 0.925)$ is substituted for Equation 9, and the square is taken, the extraction coefficient M_{EL} of the EL light intensity can be expressed as follows.

[0092]

$$M_{EL} = (m_{EL})^2 = 1.906^2 = 3.63 \qquad \ldots (18)$$

[0093]

The same calculation is made for Example 1. Since the rear electrode is made non-reflective, assuming that $(r_1, r_2) = (0.119, 0)$, M_{EL} is expressed as follows.

[0094]

$$M_{EL} = (m_{EL})^2 = 0.889^2 = 0.78 \qquad \dots (19)$$

[0095]

As can be seen from Fig. 7, the brightness in Example 1 is 0.23 times as large as that in Example 2. This is approximately equal to the calculation result of the ratio between the extraction coefficients M_{EL}, i.e. 0.78/3.63 = 0.21.

[0096]

Example 3

As Example 3, an organic EL device with the measured intensity reflectivity R = 0.12, i.e. $r_2 = (0.12)^{1/2} = 0.346$ was made, like Example 1, by adjusting the thickness of the Alq_3 layer which is the second transparent layer of the non-reflective electrode. In the external light EL light intensity is $154 cd/m^2$ and the brightness ratio to that in Example 2 was 0.48.

[0097]

If $(r_1, r_2) = (0.119, 0.346)$ is substituted for Equation 9, and the square is taken, the extraction coefficient M_{EL} of the EL light intensity can be expressed as follows.

[0098]

$$M_{EL} = (m_{EL})^2 = 1.237^2 = 1.531$$

Therefore, its ratio to the calculated value in Example 2 is 1.531/3.63 = 0.422. This value is substantially equivalent to the actual brightness 0.48. Table 3 shows the measured results in Examples 1 to 3. As can be seen, the calculated value and the measured value are fairly identical to each other.

[0099]

[Table 3]

	Electric Field Reflectivity		EL Light External Extracting Intensity		Intensity Ratio Normalized by Example 2	
	r_1	r_2	Calculated Value	Measured Value 7.5mA/cm^2	Calculated Value	Measured Value
Example 1	0.119	0	0.78	77	0.215	0.24
Example 2	0.119	0.925	3.63	312cd/m^2	1	1
Example 3	0.119	0.346	1.53	154	0.422	0.48

[0100]

Examples 4 and 5

As Example 4, the non-reflective laminated structure was made on the same condition as Example 3, and its reflectivity was measured. As Example 4, the EL device having the glass/non-reflective laminated structure was made and as Example 5, the EL device having glass/ITO/non-reflective laminated structure was made. Their intensity reflectivities were measured.

[0101]

In Example 5, the intensity reflectivity was about 10 %. Therefore, the amplitude reflectivity of the non-reflective laminated structure can be estimated as $(0.1)^{1/2} = 0.316$. On

the other hand in Example 4, the intensity reflectivity was about 5 %. On the basis of Example 5, the external light reflectivity in Example 4 was calculated by substituting $(r_1, r_2) = (0.119, (0.1)^{1/2}) = (0.119, 0.316)$ for Equation (14). Its value $M_{external\ light} = (m_{external\ light})^2 = 4.19$ % which is fairly identical to the measured value about 5%.

[0102]

Table 2 shows that in the organic EL device, (r_1, r_2) giving non-reflectivity to the external light is $r_1 = r_2$. Table 1 shows that at $r_1 = r_2$, the extraction coefficient of the EL light $M_{EL} = 1$.

[0103]

Now, in the case of $(r_1, r_2) = (0.1, 0.35)$, $M_{EL} = 1.59$ and $M_{external\ light} = 6.7$ % can be obtained. It can be seen that the EL efficiency could be improved 1.96 times as large as $M_{EL} = 0.81$ and $M_{external\ light} = 1.0$ % in the case of $(r_1, r_2) = (0.1, 0)$.

[0104]

Example 6

As Example 4, like Example 1, a plurality of organic EL devices with an electrode having intensity reflectivities changed by adjusting the thickness of a thin aluminum layer which is the first transparent layer of the non-reflective electrode.

[0105]

Fig. 12 shows the distribution of brightness efficiency and curve calculated by Equation (9). As seen from Fig. 12, for various $R2 = (r_2)^2$, the EL intensity of an actual device is fairly identical to the calculation result in Equation (9).

[0106]

As seen from Fig. 12, when the rear intensity reflectivity increases from 0 to 10 %, the brightness increases greatly by 1.79 times from about 70 cd/m^2 to 125 cd/m^2. Namely, the device efficiency of the organic EL device increases approximately twice. In this way, compared to the case where the rear reflectivity is 0, it can be seen that even if the rear intensity reflectivity increases slightly, the device efficiency increases greatly.

[0107]

Now referring to Tables 1 and 2, comparison is made between the case of non-reflection of the external light and the case of slight remaining reflection. As can be seen from Table 2, in the organic EL device, (r_1, r_2) which gives non-reflection to the external light is $r_1 = r_2$. As can be seen from Table 1, if $r_1 = r_2$, the extraction coefficient of the EL light $M_{EL} = 1$.

[0108]

Now, assuming that $(r_1, r_2) = (0.1, 0.35)$ (there is remaining reflection), $M_{EL} = 1.59$, $M_{external\ light} = 6.7$ %. This shows that the extraction efficiency of the EL light is increased

by 1.96 times as compared with M_{EL} = 0.81 and $M_{external\ light}$ = 1.0 % in the case where (r_1, r_2) = (0.1, 0). Thus, it can be understood that where there is the slight remaining reflection, the extraction efficiency of the EL light is greatly improved as compared with the case of non-reflection of the external light.

[0109]

It is desired that the intensity reflection coefficient R_2 in the rear reflection area is adjusted so that the external light intensity reflectivity $M_{external\ light}$ in the display seen from a viewer is 10 % or less owing to optical interference effect. It is preferred that the intensity reflectivity R_2 is adjusted in the range of 5 - 50 % to intensify the efficiency of externally extracting the EL light. When the external light intensity reflectivity $M_{external\ light}$ in the display seen from a viewer exceeds 10 %, the increase in the external light reflectivity plays a greater role than the increase in the extraction efficiency of the organic EL light, thereby deteriorating the visibility of the display.

[0110]

The combinations of (r_1, r_2) which satisfies the condition that the external light intensity reflectivity $M_{external\ light}$ in the display seen from a viewer is 10 % or less are the numerical values within the range in the vicinity of the diagonal line which can be drawn from the upper left corner to the lower right corner in Table 2. On the basis of Equation (16), this range

can be expressed by

[0111]

[Equation 7]

$$\left(\frac{r_1 - r_2}{1 - r_1 r_2}\right)^2 \leq 0.1 \qquad \dots (20)$$

[0112]

[Equation 8]

$$\left(\frac{\sqrt{R_1} - \sqrt{R_2}}{1 - \sqrt{R_1 R_2}}\right)^2 \leq 0.1 \qquad \dots (21)$$

[0113]

If the numerical values within this range are selected to improve the intensity transmissivity M_{EL} of the EL light with reference to Table 1, the display with the reflectivity of the external light suppressed and the light emitting intensity of the EL light increased can be acquired. Preferably, among the parameters located on the lower left side of the diagonal line which can be drawn from the upper left corner to the lower right corner in Table 1, the parameters may be selected which provide the external light intensity reflectivity $M_{external\ light}$ of 10 % or less. Referring to Table 1, this range can be expressed by

[0114]

$r_1 \leq r_2 \qquad \dots (22)$

$R_1 \leq R_2$ … (23)

[0115]

In summary, the display is preferably adjusted so that the external light intensity reflectivity $M_{external\ light}$ is 10 % or less, and parameter $r_1 \leq r_2$, i.e. $R_1 \leq R_2$. Such a display which can satisfy this condition can be the display with the reflectivity of the external light suppressed and the light emitting intensity of the EL light increased. In this configuration, the light emitting intensity of the organic EL display can be increased in the state where the current flowing through the organic layer has been decreased.

[0116]

Embodiment 1

Now referring to Fig. 13, an explanation will be given of a first embodiment of this invention.

[0117]

Fig. 13 is a view showing an organic EL device 30 according to the first embodiment of this invention. The organic EL device 30 includes a glass substrate 31, a transparent electrode 32 arranged on the glass substrate 31, an organic layer 34 consisting of a plurality of layers successively stacked on the transparent electrode 32 and a rear electrode 33 stacked on the organic layer 34. Application of a voltage between the transparent electrode 32 and the rear electrode 33 injects positive and negative carriers into the device, and the

re-combination of these carriers generates the electroluminescence within the organic layer 34. Reference numeral 35 denotes one of light emitting sources which emit the light in the organic layer 34 when the excited organic molecules returns to the ground state, and has a size corresponding to approximately a single molecule. These light emitting sources 35 are distributed infinitely as a layer. The luminescent light emitted from the infinite number of light emitting sources 35 are radiated directly or by multiple reflection within the device toward a viewer 36 through the transparent electrode 32 and the glass substrate 31.

[0118]

In this embodiment, between the interface between the rear electrode 33 and the organic layer 34, and the light emitting intensity peak position of the light emitting source 35, and between the interface between the transparent electrode 32 and the substrate 31, and the light emitting intensity peak position of the light emitting source 35, optical distances are selected so as to increase all the multiply-reflected light beams within the device.

[0119]

The transparent electrode 32 is made of indium tin oxide (ITO). The transparent electrode 32 may be other transparent conductive films.

[0120]

The electric field amplitude reflectivity r_1 at the interface between the transparent electrode 32 and the glass substrate 31 can be estimated at 0.119. The electric filed amplitude reflectivity at the interface between the transparent electrode 32 and the organic layer 34 of 0.043, which is smaller than 0.119, is negligible. The electric field amplitude reflectivity r_2 at the interface between the organic layer 28 and the rear electrode 27 can be estimated at 0.346. In this case, the measured M_{EL} and $M_{external\ light}$ are 1.531 and 3.63 %. If r_2 equals 0, since M_{EL} is approximately 0.8, the brightness of the EL light emitting intensity is increased approximately twice. In this embodiment, the condition for improving the extraction coefficient M_{EL} of the EL light is $r_1 \leq r_2$ from Table 1 and 2. In addition, if r_2 is 0.4 or less, the device with the external light intensity $M_{external\ light}$ of 10 % or less can be obtained.

[0121]

In this embodiment, it means that where the external light intensity $M_{external\ light}$ is adjusted to 10 % or less, particularly, approximately 0, the organic EL device itself is a non-reflector having a non-reflecting structure. In this way, in this embodiment, using the reflecting plane formed on the side nearer than the light emitting layer to the viewer and the reflecting plane formed on the side farther than the light emitting layer from the viewer, a low reflecting structure or non-reflecting

structure has been realized.

[0122]

Embodiment 2

The first embodiment relates to the case where the EL light is extracted toward the substrate. The above contemplation applies, as it is, to a top emission type EL organic EL device which extracts the EL light toward the side opposite to the substrate. Fig. 14 is a view showing the top emission type EL organic EL device. Referring to Fig. 14, a detailed explanation will be given of the top emission type EL organic EL device.

[0123]

The top emission type organic EL device 40 includes a substrate 41, a rear electrode 42 arranged on the substrate 41, an organic layer 44 consisting of a plurality of layers successively stacked on the rear electrode 42 and a transparent electrode 43 stacked on the organic layer 44. The transparent electrode 43 may be a laminated structure consisting of a transmissive metal and a conductive oxide film. The transparent electrode 43 is made of sputtered ITO.

[0124]

The electric-field amplitude reflectivity r_1 on the front electrode when the EL light is extracted from the transparent electrode 43 into the air is expressed by

[0125]

$$r_1 = (n_{ITO} - n_{air}) / (n_{ITO} + n_{air})$$
$$= (1.93 - 1.0)/(1.93 + 1.0)$$
$$= 0.317$$

[0126]

Table 4 shows the relationship among the electric-field amplitude reflectivity r_2 and intensity reflectivity R_2 on the rear (substrate side) and outdoor intensity reflectivity $M_{external\ light}$ and the EL intensity extraction coefficient M_{EL}.

[0127]

[Table 4]

r_2	R_2	$M_{external\ light}$	M_{EL}
0	0	0.100	0.407
0.317	0.100	0.0	1.00
0.575	0.331	0.100	1.73

[0128]

The condition for setting the external light intensity reflectivity $M_{external\ light}$ at 10 % can be solved noting the sign of Equation (14). This corresponds to R_2 = 0 % and 33.1 %. In this case, by applying the condition $R_1 = R_2$ described in Claim 2, the EL light intensity extraction coefficient can be set at 1.73. This value is equal to 4.25 times as large as in the case of the intensity reflectivity R_2 = 0 % at the rear electrode.

[0129]

Modified Embodiment

In the top emission type organic EL device, as shown in

Fig. 15, the rear electrode may be a laminated structure consisting of a transmissive conductive film and a lowly-reflective film.

In other words, in the transmissive type organic EL device with both electrodes being transmissive, also where an absorptive film is applied on the rear plane opposite to the light extracting side, r_2 can be taken as the reflectivity.

[0130]

In the top emission type organic EL device, as shown in Figs. 16 and 17, the light extracting electrode may be a laminated structure consisting of a transmissive conductive film and semi-transmissive film. Equation (14) relates to the case where the absorption of energy at the first reflecting plane from the external light is zero. However, another absorption layer may be formed at the interface for adjusting t_1 independently from r_1.

[0131]

As the device format similar to Example 1, as shown in Fig. 18, the rear electrode may be formed of a laminated structure consisting of a transmissive conductive film and a lowly-reflective film.

[0132]

As shown in Fig. 19, where there are a plurality of reflecting planes on the rear surface or front surface, the sum of the light beams from all the reflecting planes located

at the rear surface or front surface may be defined as the reflected light, and the change in the electric field amplitude may be defined as r_1 or r_2.

[0133]

As shown in Fig. 20A, the structure of the non-reflector (i.e. laminated optical structure with a low reflectivity and a low transmissivity) may be an organic EL device itself. In Fig. 20, a transparent electrode 51 which is made of a semi-transmissive film is located on the substrate. A semi-transmissive organic EL layer 52 having at least a light emitting layer is stacked on the organic EL layer 52. A reflective rear electrode 53 is stacked on the organic EL layer 52.

[0134]

In this arrangement, the transparent electrode 51, organic EL layer 52 and rear electrode 53 constitute a non-reflector which is adjusted to cancel the external light incident from the side of the substrate by its optical interference with the reflected light beams at the interfaces between the adjacent layers. In such an organic EL device, r_1 and r_2 may be adjusted to set the external light intensity reflectivity $M_{\text{external light}}$ at 10 % or less.

[0135]

It is needless to say that the above arrangement can be applied to the top emission type organic EL device in such a

manner that the electrode 51 arranged on the substrate is a reflective rear electrode and the electrode 53 is a semi-transmissive electrode.

[0136]

In this way, if the organic EL device itself is constituted as the non-reflector, it is not necessary to provide separately a semi-transparent member or optical reflective film so that the organic EL device can be low-profiled. Since provision of other members are not required, the manufacturing process can be simplified and the production efficiency can be improved.

[0137]

As shown in Fig. 20B, the structure of the non-reflector (i.e. laminated optical structure with a low reflectivity and a low transmissivity) may include a portion of the organic EL device so that the one end of the non-reflector is formed of a portion of the organic EL device. In Fig. 20B, a transparent electrode 61 which is made of a semi-transmissive film is located on the substrate. A transmissive organic EL layer 62 having at least a light emitting layer is stacked on the transparent electrode 61. The organic EL layer 62 incorporates an optical reflective film 63 having the property of charge transportation and semi-transmissivity. A reflective rear electrode 64 is stacked on the organic EL layer 62.

[0138]

In this arrangement, the optical reflective film 63 and

rear electrode 64 constitute a non-reflector which is adjusted to cancel the external light incident from the side of the substrate by its optical interference with the reflected light beams at the interfaces between the adjacent layers. In this arrangement, the reflected light at the interface between the substrate and the transparent electrode 61 and the reflected light at the interface between the transparent electrode 61 and organic EL device, which have a very small amount, are negligible. In such an organic EL device, r_1 and r_2 may be adjusted to set the external light intensity reflectivity $M_{external\ light}$ at 10 % or less.

[0139]

In this way, since the non-reflector has a part of the organic EL device, the number of the semi-transmissive optical members and optical reflective films to be formed can be reduced so that the organic EL device can be low-profiled. Since provision of other members are not required, the manufacturing process can be simplified and the production efficiency can be improved.

[0140]

In accordance with the organic EL display described hitherto, the light emission efficiency of the organic EL light can be enhanced without using a circularly-polarizing filter while improving the contrast of the organic EL display. Further, the light emission efficiency of the organic EL display can

be enhanced in the state where the current flowing through the organic layer has been decreased.

[Brief Description of the Drawings]

[Fig. 1] Fig. 1 is a view showing a sectional structure of the organic EL device in an organic EL display and a distribution of the intensity of the EL light emitted internally within the organic EL device.

[Fig. 2] Fig. 2 is a view for explaining the optical interference within the device of the light radiated from an internal EL emitting point.

[Fig. 3] Fig. 3 is a view showing the method for optically optimizing the organic EL device structure.

[Fig. 4] Fig. 4 is a view showing a non-reflective laminated structure of a plurality of stacked optical films.

[Fig. 5] Fig. 5 is a graph showing the wavelength and reflectivity of a non-reflective laminated structure consisting of aluminum and organic material.

[Fig. 6] Fig. 6 is a graph showing the voltage-current characteristic of each of the organic EL device having the non-reflective laminated structure (Example 1) and organic EL device with no non-reflective laminated structure (Example 2).

[Fig. 7] Fig. 7 is a graph showing the current-brightness characteristic in Examples 1 and 2.

[Fig. 8] Fig. 8 is a conceptual view of the optical model of an organic EL display.

[Fig. 9] Fig. 9 is a view illustrating the multiple reflection of the light radiated internally in the device and the electric-field amplitude of the light externally extracted from the device in the configuration of Fig. 8.

[Fig. 10] Fig. 10 is a conceptual view of the multiple interference phenomenon in the organic EL device about incident external light.

[Fig. 11] Fig. 11A and 11B are views showing the inversion state of the phase of light.

[Fig. 12] Fig. 12 shows the distribution of brightness efficiency and curve calculated by Equation (9).

[Fig. 13] Fig. 13 is a view showing an organic EL device according to the first embodiment of this invention.

[Fig. 14] Fig. 14 is a view showing an organic EL device according to the second embodiment of this invention.

[Fig. 15] Fig. 15 is a view showing an organic EL device according to a modification of this invention.

[Fig. 16] Fig. 16 is a view showing an organic EL device according to another modification of this invention.

[Fig. 17] Fig. 17 is a view showing an organic EL device according to still another modification of this invention.

[Fig. 18] Fig. 18 is a view showing an organic EL device according to a further modification of this invention.

[Fig. 19] Fig. 19 is a view showing an organic EL device according to a still further modification of this invention.

[Fig. 20] Figs. 20A and 20B are views showing an organic EL device according to a further modification of this invention.

[Description of Reference Numerals and Signs]

1, 31	substrate
2, 32, 43, 51, 61	transparent electrode
3, 33, 42, 53, 64	rear electrode
4, 34, 44, 52, 62	organic layer
5	light emitting layer
6, 35, 45	light emitting point
7, 36, 46	viewer
8	EL light
9a	first forward radiated light
9b	first rearward reflected light
11	rear reflecting plane
12	front reflecting plane
13	glass substrate
14	first semi-transmissive layer
15	second semi-transmissive layer
16	highly reflective layer
18a	reflected light from a first semi-transmissive layer
18b	reflected light from a highly reflective layer
19	rear reflecting area
20	front reflecting area
22a	incident external light beam

22b	first reflecting external light beam
22c	first permeating light beam
23	synthesized light beams by multiple reflection
30, 40	organic EL device
63	optical reflecting film

[Designation of Document] Abstract

[Abstract]

[Problem] In an organic EL device using light extracted on at least either side, to provide a method for increasing intensity of organic EL light externally extracted when a technique of reducing the reflectivity on a rear plane to improve visibility of the display, and an organic EL display using this method.

[Means for Resolution] An organic EL display equipped with an organic EL device with an organic material sandwiched by at least two electrodes, comprising: a light emitting layer which emitting light; a front reflecting area arranged on the side of a viewer with respect to the light emitting layer; and a rear reflecting area arranged on the side opposite to the viewer with respect to the light emitting layer, wherein the optical film thickness of the organic material, intensity reflectivity R_1 at the front reflecting area and intensity reflectivity R_2 at the front reflecting area are adjusted so that the external light intensity reflectivity of the display viewed from the viewer is 10 % or less by an optical interference effect.

[Selected Drawing] Fig. 12

FIG. 1

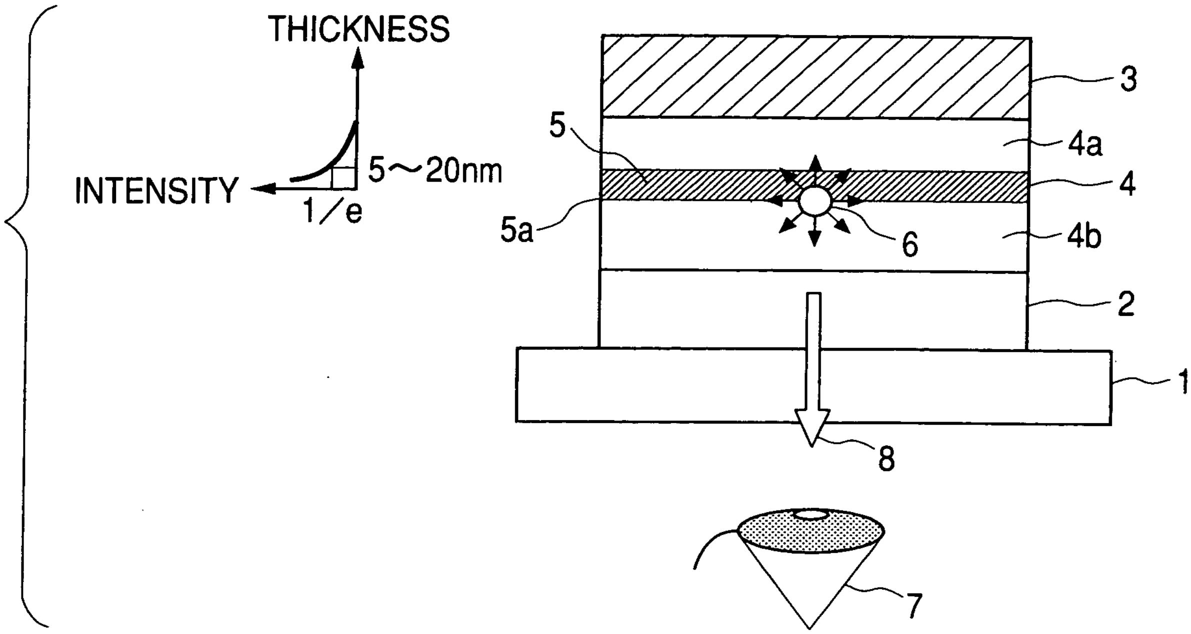

THICKNESS
INTENSITY
5～20nm
1/e
3
5
4a
4
5a
6
4b
2
1
8
7

FIG. 2

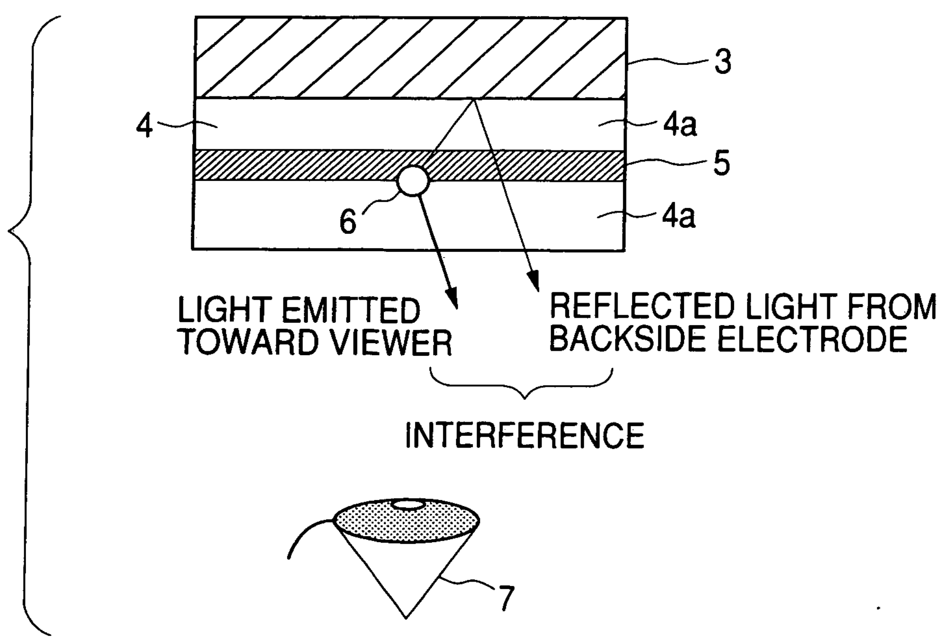

3
4
4a
5
6
4a
LIGHT EMITTED
TOWARD VIEWER
REFLECTED LIGHT FROM
BACKSIDE ELECTRODE
INTERFERENCE
7

FIG. 3

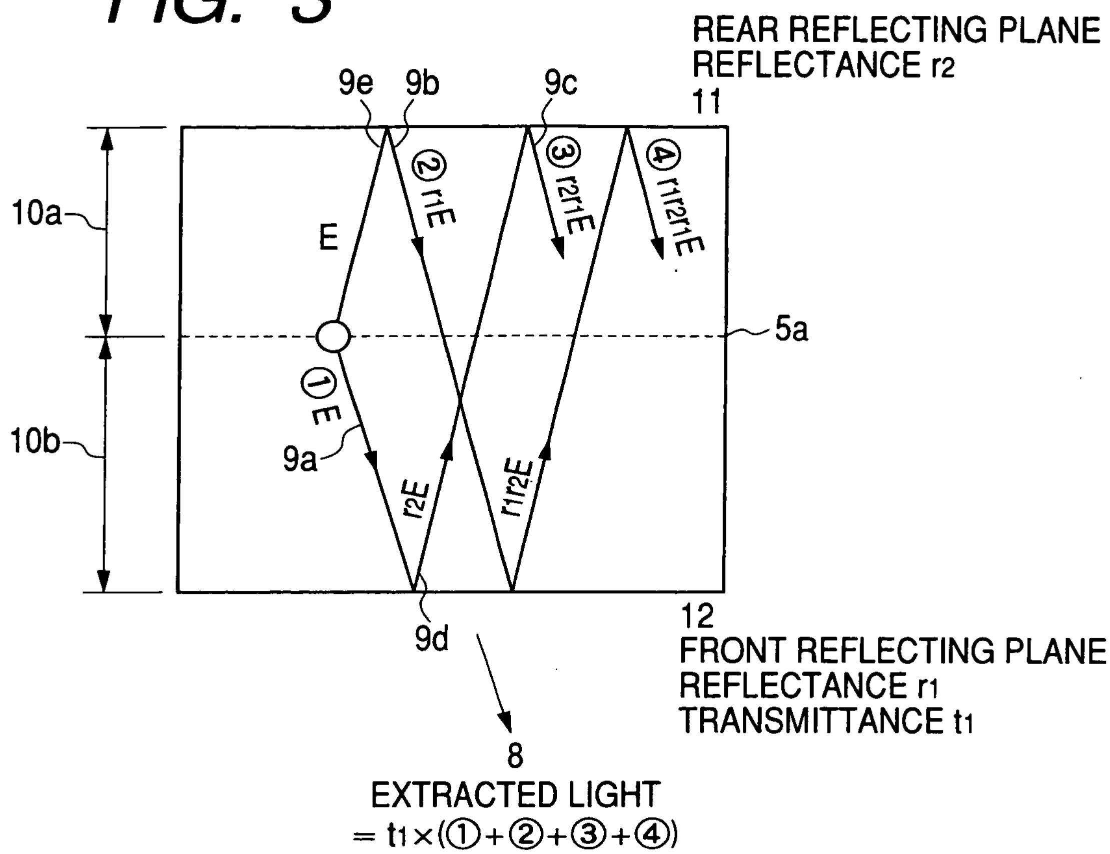

REAR REFLECTING PLANE
REFLECTANCE r2
11
9e
9b
9c
10a
E
② r1E
③ r2r1E
④ r1r2r1E
5a
① E
10b
9a
r2E
r1r2E
12
9d
FRONT REFLECTING PLANE
REFLECTANCE r1
TRANSMITTANCE t1
8
EXTRACTED LIGHT
= t1×(①+②+③+④)

FIG. 4

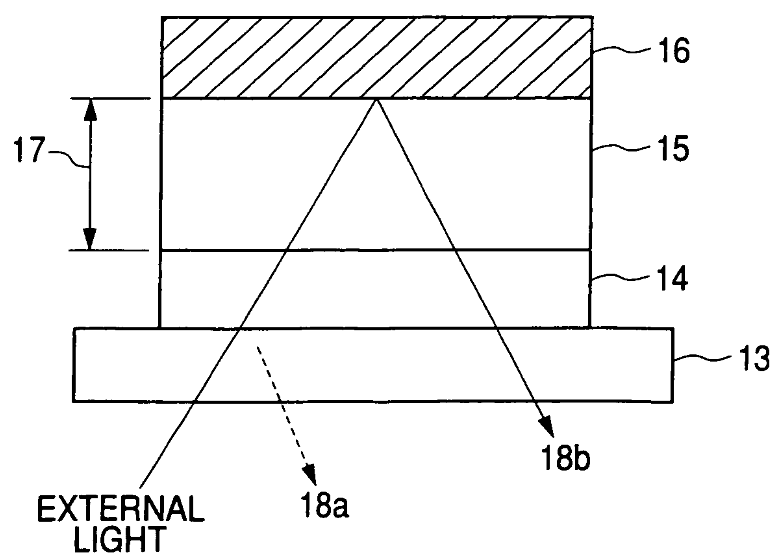

16
17
15
14
13
18b
EXTERNAL
LIGHT
18a

FIG. 5

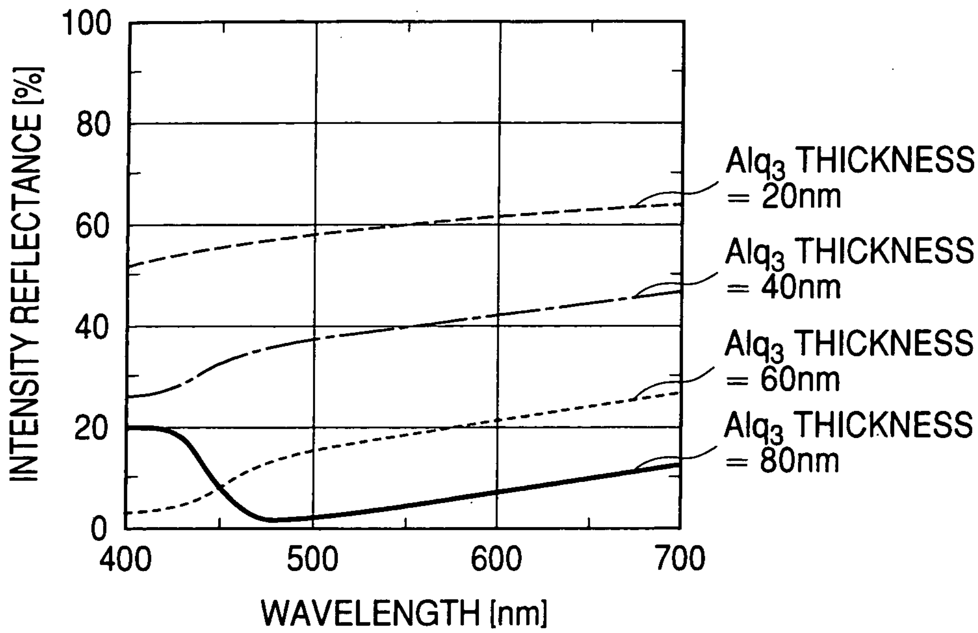

100
80
60
40
20
0
400
500
600
700
INTENSITY REFLECTANCE [%]
WAVELENGTH [nm]
Alq_3 THICKNESS = 20nm
Alq_3 THICKNESS = 40nm
Alq_3 THICKNESS = 60nm
Alq_3 THICKNESS = 80nm

FIG. 6

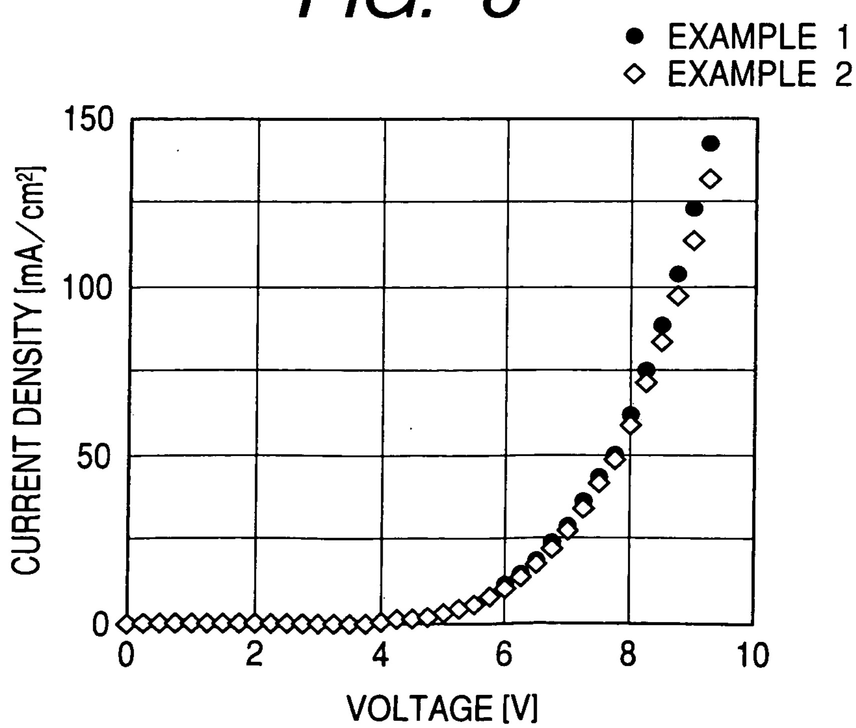
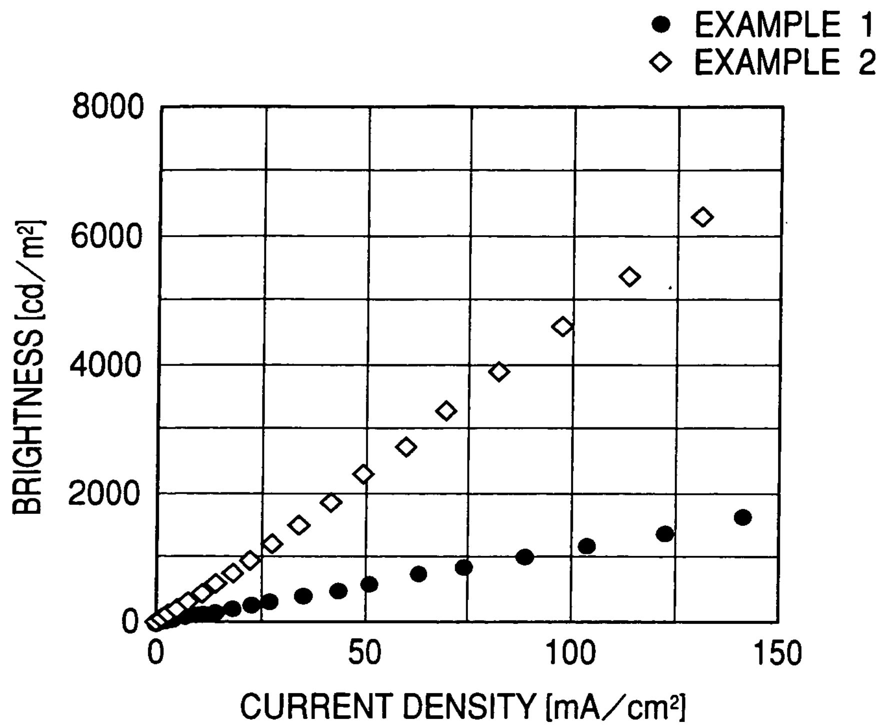
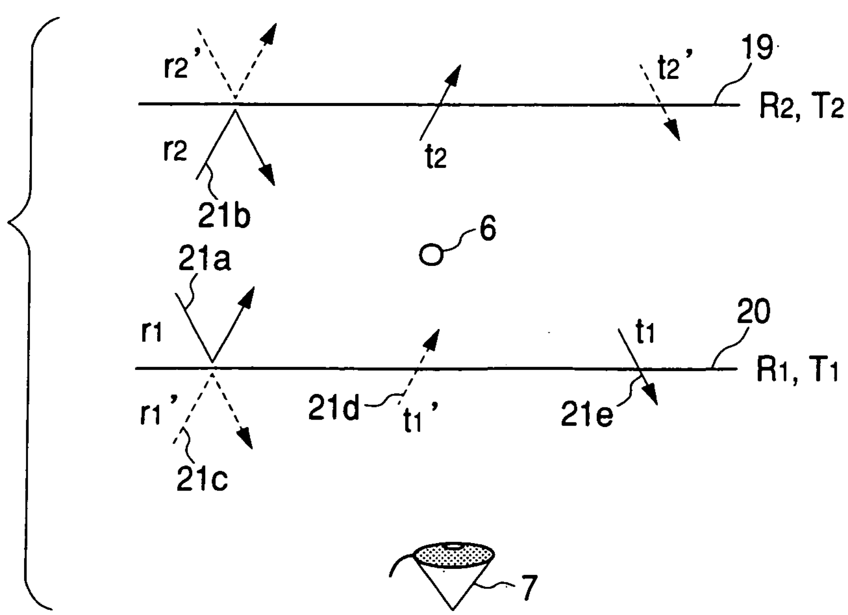

EXAMPLE 1
EXAMPLE 2
150
100
50
0
0
2
4
6
8
10
CURRENT DENSITY [mA/cm²]
VOLTAGE [V]

FIG. 7



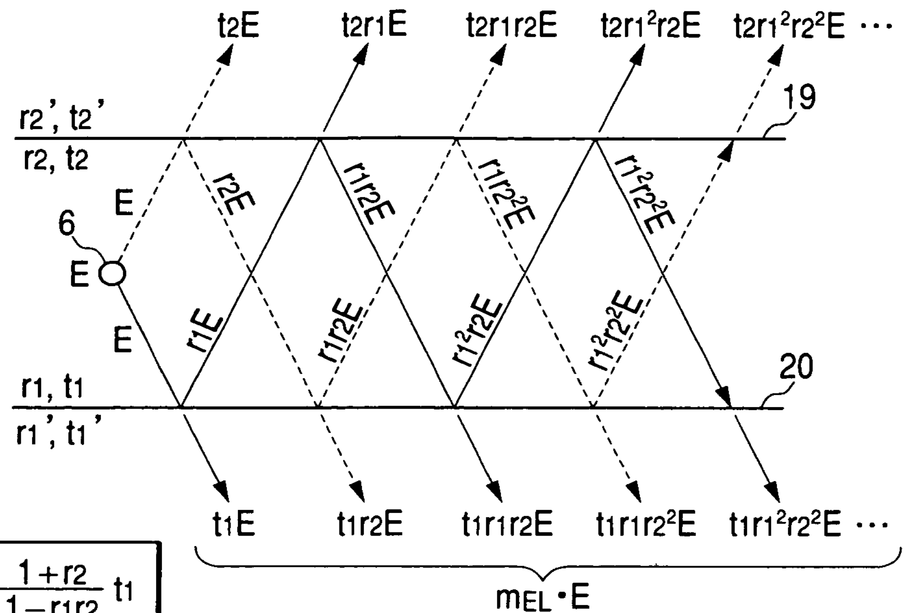
● EXAMPLE 1
◇ EXAMPLE 2
BRIGHTNESS [cd/m²]
8000
6000
4000
2000
0
0
50
100
150
CURRENT DENSITY [mA/cm²]

FIG. 8



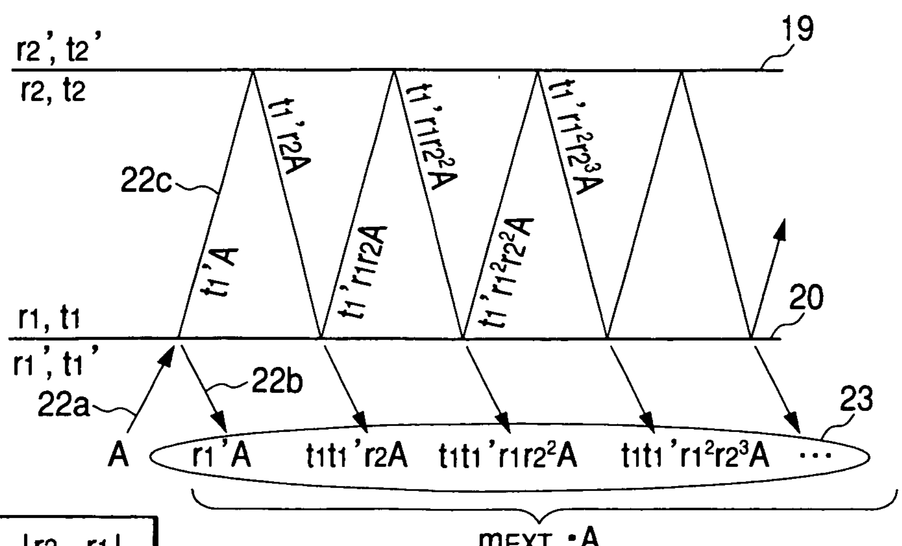
r2'
t2'
19
R2, T2
r2
t2
21b
6
21a
r1
t1
20
R1, T1
r1'
21d
t1'
21e
21c
7

FIG. 9



$$m_{EL} = \frac{1+r_2}{1-r_1 r_2} t_1$$

FIG. 10



$$m_{EXT} = \frac{|r_2 - r_1|}{1-|r_1 r_2|}$$

FIG. 11A

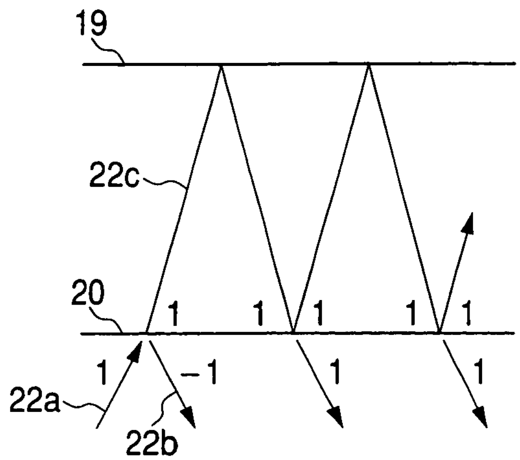


FIG. 11B

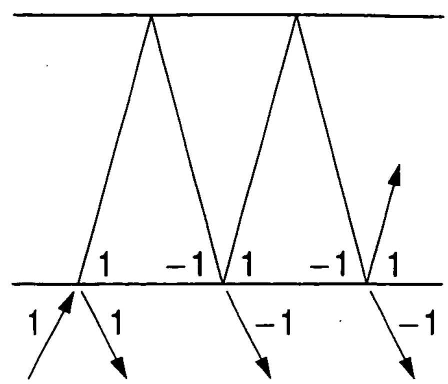


FIG. 12

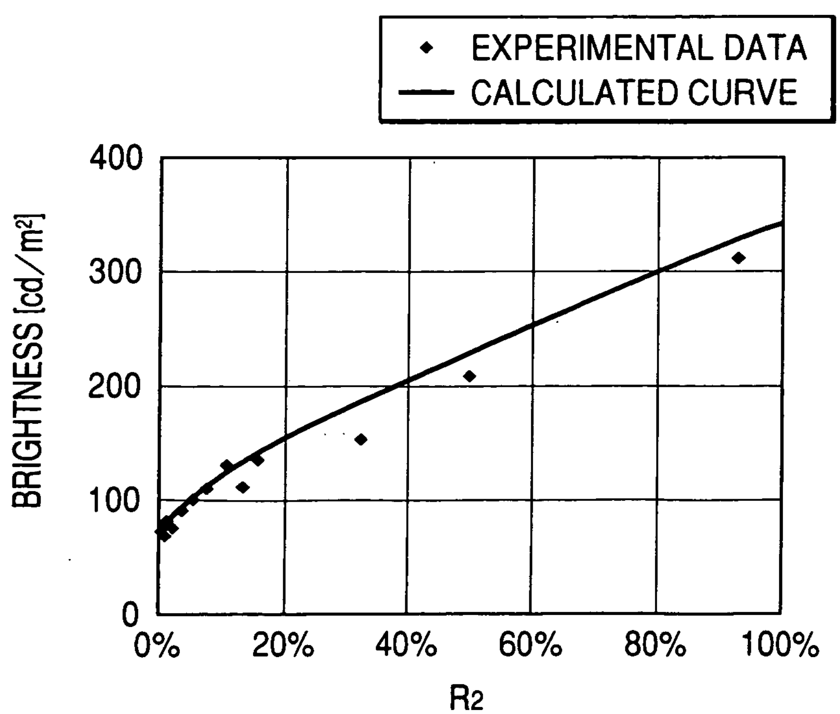


FIG. 13

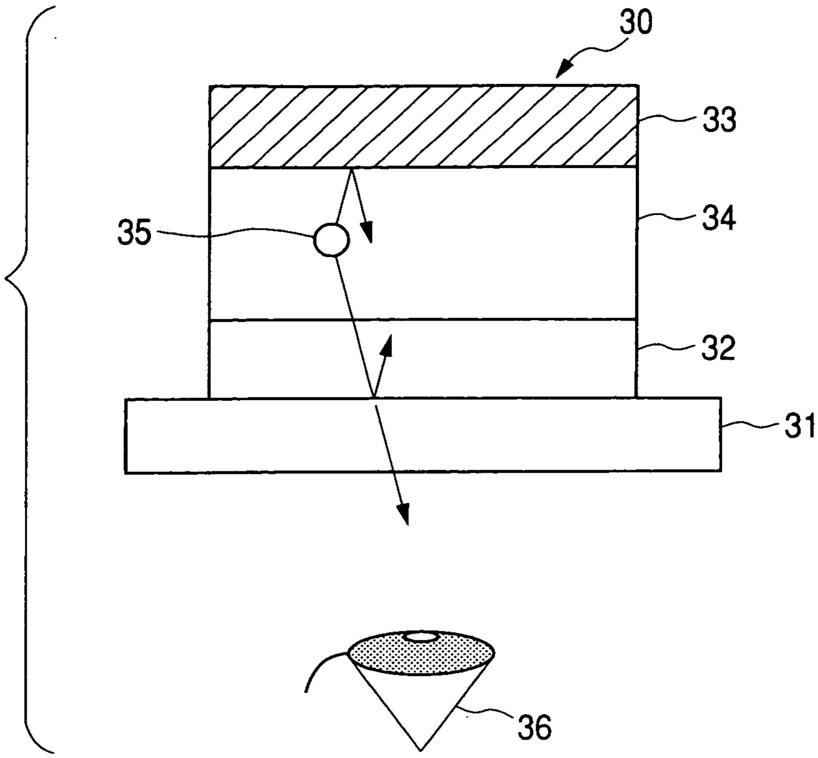


FIG. 14

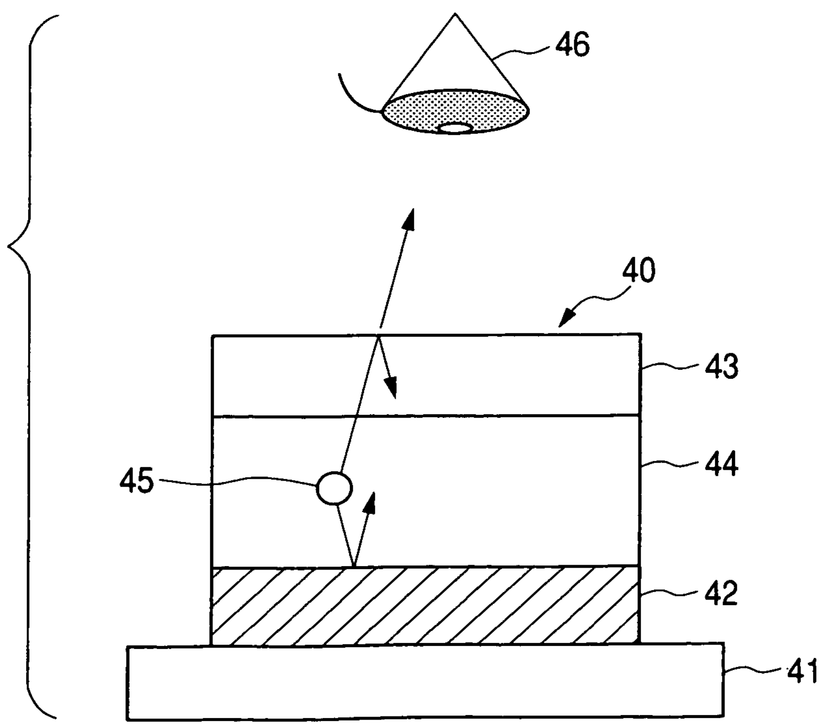


FIG. 15

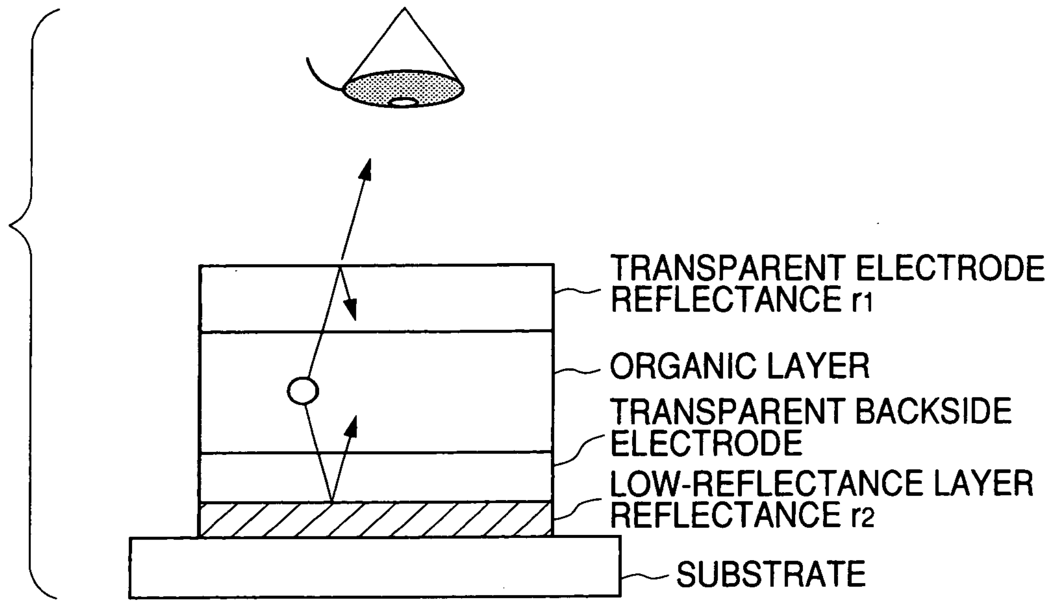

TRANSPARENT ELECTRODE
REFLECTANCE r1
ORGANIC LAYER
TRANSPARENT BACKSIDE
ELECTRODE
LOW-REFLECTANCE LAYER
REFLECTANCE r2
SUBSTRATE

FIG. 16

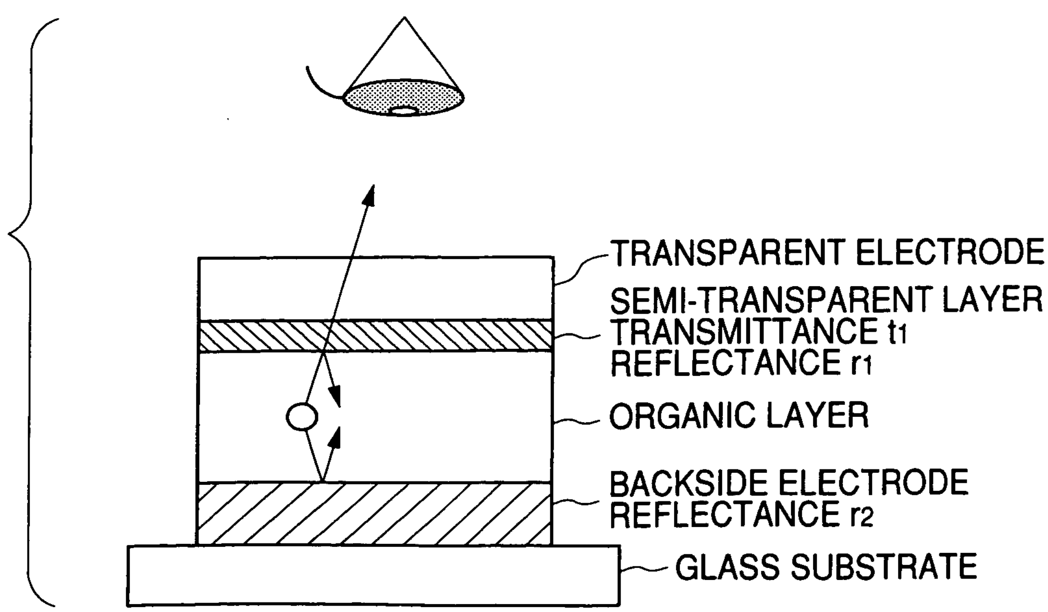

TRANSPARENT ELECTRODE
SEMI-TRANSPARENT LAYER
TRANSMITTANCE t1
REFLECTANCE r1
ORGANIC LAYER
BACKSIDE ELECTRODE
REFLECTANCE r2
GLASS SUBSTRATE

FIG. 17

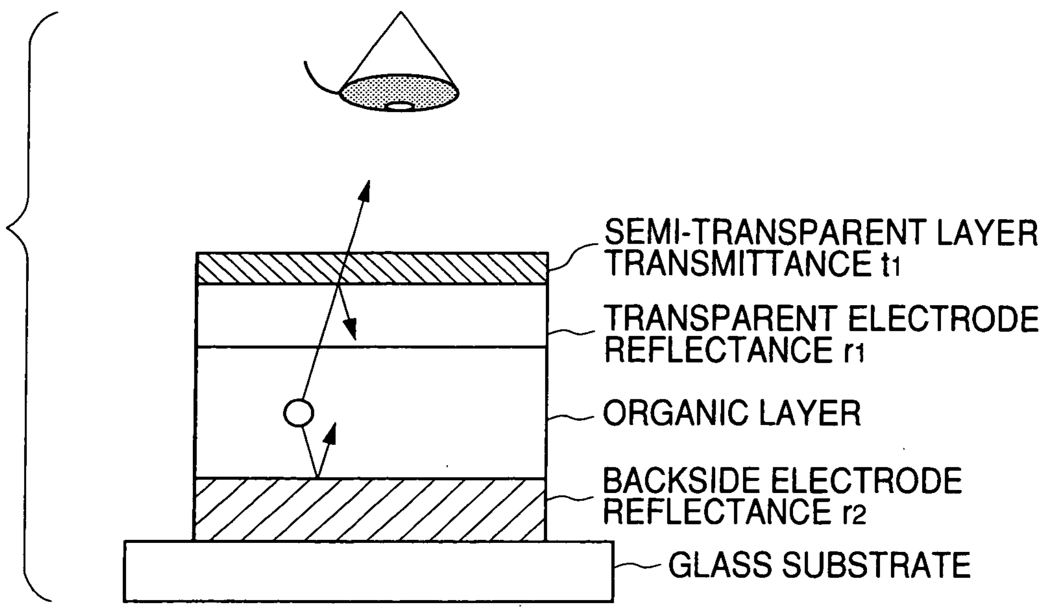

SEMI-TRANSPARENT LAYER
TRANSMITTANCE t1
TRANSPARENT ELECTRODE
REFLECTANCE r1
ORGANIC LAYER
BACKSIDE ELECTRODE
REFLECTANCE r2
GLASS SUBSTRATE

FIG. 18

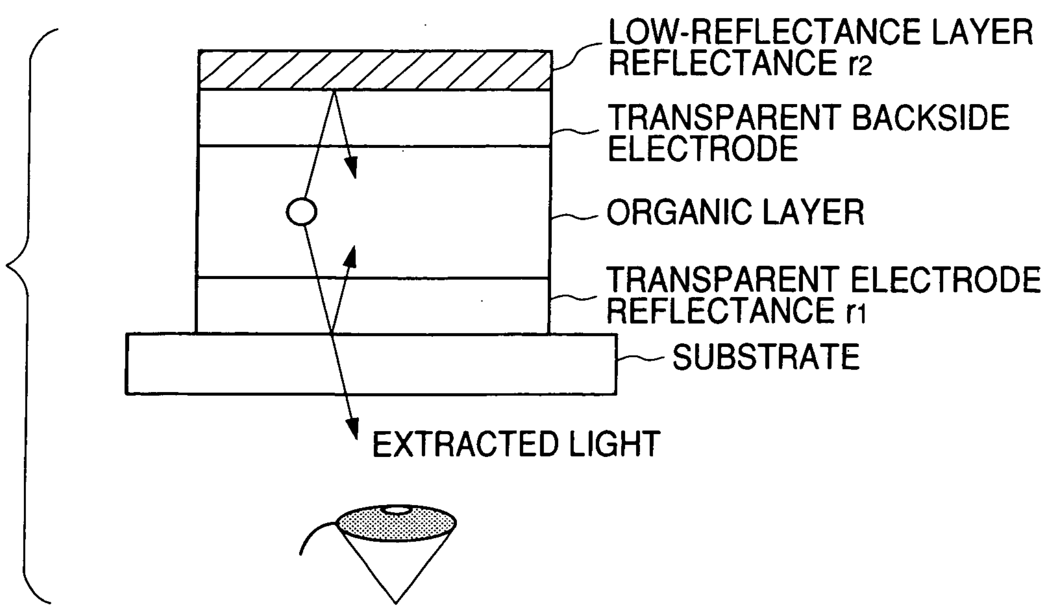

LOW-REFLECTANCE LAYER
REFLECTANCE r2
TRANSPARENT BACKSIDE
ELECTRODE
ORGANIC LAYER
TRANSPARENT ELECTRODE
REFLECTANCE r1
SUBSTRATE
EXTRACTED LIGHT

FIG. 19

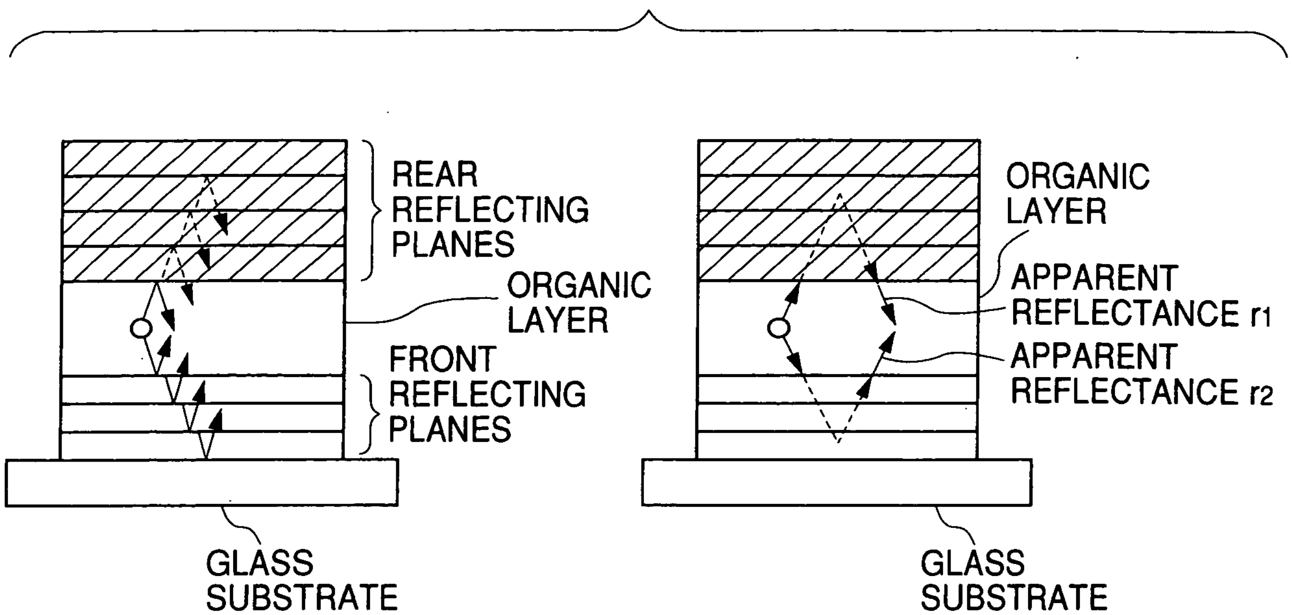


FIG. 20A

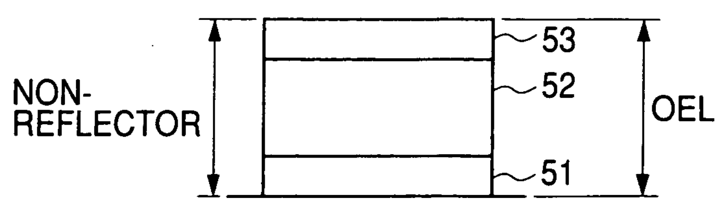


FIG. 20B